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REMOVAL OF WATER SUPPLY
CONTAMINANTS - ARSENIC,
BY FRANCIS J. AMORE :
TECHNICAL LETTER 16

Subject: Technical Letter 16 February 1977
Removal of Water Supply Contaminants -- Arsenic

This is the second of a series of Technical Letters dealing with state of the art methods for removal of contaminants from water supplies so that the supply will be in compliance with state and federal drinking water standards.

Contaminant

This Technical Letter is concerned with arsenic as a contaminant of drinking water. At the present time, the State Environmental Protection Agency (EPA) reports eleven water supplies which exceeded the allowable level of 0.05 milligram per liter (mg/1) for arsenic in 1976. The levels vary from 0.18 to 0.06 mg/l and are found in scattered sites around the state.

Prevalence and Uses

Arsenic is found in groundwater supplies due to leaching of geological deposits or due to contamination from industrial or agricultural usage.

Arsenic is rather ubiquitous and abundant on the earth's crust and in the biosphere. Average soil levels of arsenic are 1 to 5 micrograms per gram (µg/g) primarily in the pentavalent form. Arsenic is also associated with many sulfide ores generally in the trivalent oxidation state or as arsenides. Because of its association with ores, arsenic is a by-product of many smelting operations with significant amounts being released as arsenic trioxide.

Arsenic has found widespread use in industry and agriculture. It has been used in paints and dyes, and in tanning; as an insecticide (i.e., fly killer, weed killer, and cattle dip); as a wood preservative and as a taxidermy preservative; in veterinary medicine as a growth stimulator for pigs and poultry; and for medicinal purposes primarily against various parasites. Arsenic is also used as an alloy with other metals most notably with lead to produce a spherical, hardened shot.

Health Effects

Concern over arsenic in drinking water is based on the known acute and chronic toxicity of arsenic. The trivalent form is far more toxic than the

pentavalent or elemental arsenic forms. Pentavalent arsenic is the predominant species found in water.

Toxicological consideration of arsenic in water is based on chronic effects rather than acute toxicity. Chronic exposure to arsenic compounds results in general weakness, nausea, vomiting, nose bleed, bleeding gums, hoarseness, coughing, dermatitis, severe skin exfoliation, kidney and liver damage and degeneration, foot and wrist drop, loss of hair, tremors, and convulsions.

Maximum Level

The maximum allowable level of arsenic in drinking water is 0.05 mg/1

Removal

Arsenic whether in the trivalent or pentavalent state will be found as an anionic species in water, i.e., AsO_2- or AsO_4^{-3}. Both species are relatively insoluble except as the sodium or potassium salts. Any procedure which can effectively remove anionic species from solution should be useful for the reduction of arsenic to a safe level.

A. Coagulation

Ferric chloride ($FeCl_3$) coagulation has been reported to be effective in the reduction of arsenic to an acceptable level in drinking water. In the procedure the water is aerated, treated with $FeCl_3$ coagulant, allowed to settle, and filtered. The efficiency of the process is dependent on the coagulant dosage and pH of the water. The greatest efficiency for arsenic removal is in the pH 5 to 7 range. The efficiency is much less dependent on the coagulant dosage in this pH range. Coagulant dosages of 20 to 50 mg/1 have been found to be effective. Sand filtration is used for removal of the coagulated iron. Regeneration of the sand is necessary, using a sodium hydroxide wash to remove the arsenic. The regeneration schedule is dependent on the amount of arsenic in the raw water and the amount of water treated. Cost of treatment is also dependent on the level of arsenic reduction necessary and the amount of water treated. In most situations cost will be $0.10 per cubic meter ($m^3$) (264.2 gallons) or less. Some improvement in removal is achieved if the water is oxidized with chlorine before coagulation. The importance of this additional treatment would have to be evaluated on the basis of the individual supply.

Ferrous sulfate ($FeSO_4$) can also be used, although the efficiency of removal is somewhat lower than for ferric chloride. The same dosage and pH dependence is noted.

Alum coagulation is also effective in removing arsenic. Its efficiency for arsenic removal is not as good as the iron coagulants. Its adequacy for a given water supply would have to be evaluated on a pi lot scale.

B. Lime Soda Softening

Lime softening has been shown to be useful in the removal of arsenic. The efficiency of the process is dependent on the pH and the amount of arsenic in the raw water. A pH of 9.5 to 10 is necessary for efficient arsenic removal, provided that the arsenic level does not exceed 1.0 mg/1. The utility of the process will also be affected by the characteristics of the raw water.

C. Adsorption Processes

In an adsorption process the arsenic is removed by adsorption onto the surface of a solid in contact with the water. The adsorption involves the interaction between arsenic and active sites on the solid. The arsenic becomes tightly bound to the surface and is removed from solution. Two materials have been used effectively for arsenic removal: activated alumina and bone char.

In the activated alumina process the raw water is passed through a column of activated alumina. The amount of arsenic in the finished water is monitored to determine when the column needs regeneration. The efficiency of removal is dependent on the pH and the flow rate. The pH should be maintained around 7.0. The flow rate would have to be determined on the basis of the amount of arsenic to be removed, water flow required for normal operation, and frequency of regeneration considered acceptable. The amount of arsenic removed from the alumina during regeneration is not equivalent to the amount removed from the water until the column has passed through several use-regeneration cycles. This does not affect the efficiency of the process. Operating costs of the process is on the order of $15 to $50 per million gallons treated.

The bone char process is essentially the same as the activated alumina process. The primary difference is that the bone char cannot be regenerated so the material must be used on a throwaway basis. This would increase the operating costs over the alumina process.

D. Reverse Osmosis

Reverse osmosis involves the removal of soluble minerals by passage of water through a semipermeable membrane. To get water to pass through the membrane it is necessary to apply pressure to

the water containing the minerals to overcome the natural direction of the flow which would be for pure water to diffuse into the mineral-containing water. The amount of pressure necessary is dependent on the mineral content of the raw water. Although reverse osmosis can be used to reduce the arsenic level, its application is impractical and costly unless it is already in use for the treatment of brackish water. The most significant cost is plant construction. For a 1000 mVday plant (183 gpm), construction costs are about $250,000 based on 1976 costs. This cost does not include any costs for interest during construction, site and site improvement, discharge facilities, storage and delivery facilities, or any special treatment. Operating costs are about $18,000 for a plant of that capacity.

E. Eleatrodialysis

Electrodialysis involves the removal of salts by means of ion selective membranes and a d.c. current to assist transport of the ions across the membrane. There is depletion of ions on one side of the membrane if current is passed for any length of time, while there is concentration on the other side of the membrane.. Any level of desalting can be achieved by increasing the residence time or increasing the current density.

For efficient operation good water pretreatment is required. This should include coagulation of colloidal particles, oxidation of iron and soluble organics, carbon filtration, and finally acidification.

Although this process can be used for the reduction of arsenic levels, its application is impractical and costly even if other contaminants are to be removed unless the equipment is already in use or planned for use to reduce brackish water to an acceptable salt level. The cost for electrodialysis is dependent on the level of contaminant to be reduced. In general it will be more costly than reverse osmosis. The pH of the effluent may require adjustment to protect the distribution system.

F. Distillation

Distillation involves the volatilization of water to separate it from all dissolved or suspended materials which are not volatilized. Normally the water is heated under pressure to improve the thermal efficiency of the method by recovering some of the heat. This process produces water of very low dissolved solids. Since the water is corrosive to the distribution system, it is necessary to increase the salt content.. This can normally be accomplished by appropriate blending of the finished water and the raw water.

Some pretreatment of the feed-water may be necessary. Most often only deaeration is necessary, but in some situations it may be necessary to remove suspended solids and calcium and magnesium to prevent scaling.

Distillation is a relatively expensive and impractical solution for the removal of specific contaminants from water. The process involves the removal of a large volume of water from a small amount of dissolved material. This results in an unfavorable energy requirement since it is essentially independent of the contaminant level and only dependent on the amount of water to be treated. The major cost is plant construction which will be about $1.2 million for a. 1000 m^3/day plant (183 gpm) • The operating costs for energy are also high, since there is only partial heat recovery in this process.

G. Ion Exchange

Ion exchange involves the exchange of undesirable ions in the water with innocuous species. The process uses either natural or synthetic resins as the exchange media. ion exchange has been used extensively for softening of water. There are two basic types of ion exchange resins, cation and anion. The cation exchange resins remove positively charged ions, and the anion exchange resins remove negatively charged ions. By using a mixed bed resin containing both anion and cation exchange resins, it is possible to get complete demineralization. This water can then be blended with raw water to provide a finished water of the desired quality.

Since it is not possible to selectively remove arsenic from water, it is necessary to demineralize a water and blend finished water and raw water to obtain an acceptable arsenic level. For this reason, this approach is somewhat impractical for the removal of a single contaminant from a water supply unless ion exchange is already in use or planned for use to achieve other ends. The cost for an ion exchange plant is dependent on the percent reduction in contaminant. In general the cost will be one-half to one-fourth of that for a reverse osmosis plant.

General Comments

All of the removal techniques discussed above require pilot-scale testing for a specific application to determine their efficiency. Pilot-scale studies are also needed to determine what, if any, pretreatment is necessary to insure good operating efficiency. All of the processes which effectively demineralize the water require some adjustment of pH and/or hardness and alkalinity to prevent corrosion of the distribution system.

Technical Letters are issued as part of the Water Survey's continuing service to citizens of Illinois. Should you need further clarification, please let us know.

Very truly yours,

Dr Francis Amore

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